Meteorological and Wave Measurements from a Stable Research Platform at Sea

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LONG-TERM GOALS

The approach that describes air-sea exchange as interaction between a flow and a rough surface, now considered traditional, dates back to the 1950s (Charnock, 1956). Within that approach, the complex exchange processes are condensed down to exchange coefficients, thus delivering computational efficiency in large-scale numerical modeling of air-sea meteorology. However, inability to distinguish between momentum and kinetic energy transferred to waves from those transferred to currents, as well as considerable variance in the experimental estimates of the drag coefficients, show some of the applicability limits for this traditional approach. Clearly, a short-term phase-resolved wave forecasting, a goal of the High-Resolution Wave-Air-Sea Interaction project, requires a more detailed mechanistic description of the marine boundary layer dynamics with a special focus on the elements distinctly introduced by the compliant interface and the sea surface waves. While wave dynamics on the water side has already been reduced to a computationally-intensive numerical problem (Friehe et al., 2007, section III.B), the complexity of which is determined by the number of nonlinearly interacting wave modes, the wind driving of the waves on the other hand, is less understood. Current challenges include gaps in theoretical knowledge and in techniques for numerical modeling. In particular, the observational validation for most of the wind-wave interaction mechanisms proposed so far in theoretical works is lacking. The purpose of this work is to advance our understanding on these open issues.

OBJECTIVES

This project's objective is to produce a consistent-with-observations description for the structure and dynamics of the marine atmospheric boundary layer that will be suitable to incorporate in models for short-term wave prediction. We will seek to identify the significant physical processes active in the marine boundary layer and quantify their contributions to the wind-wave growth, using Hasselmann's (1965) hierarchy of mechanisms as a framework of our studies. Two of the lower order mechanisms in that framework have been addressed experimentally, while eleven of them have never been approached observationally. Some non-expandable mechanisms, such as flow separation, have received renewed interest in light of the work of P. Sullivan, NCAR. Detection of such mechanisms in measurements will be among our important objectives.

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Ensuring the practicality of wave forecasts requires that we explore both the dynamical and numerical causes of uncertainty and the propagation of that uncertainty from the radar observations of the surface, through the models and mechanisms employed, to the wave prediction results. The horizon is the natural spatial limitation for the radar, establishing a limitation for the time to produce a forecast. Understanding the uncertainty causes and propagation will let establishing the limits (horizon) of predictability and will allow formulating a criterion for an optimal compromise between dynamic completeness and computational efficiency of the forecasting models, so that the forecasts are produced within the imposed time limits.

APPROACH

Observational data collected by the field experiment will deliver information on the boundary layer dynamics and will be used to calibrate numerical models. The atmospheric pressure measurements will serve for estimating the direct energy input to the waves occurring through form drag. The wind velocity measurements will be analyzed to identify wave-turbulence interaction and its contribution to the wave growth. Recent numerical results reported by P. Sullivan have predicted instances of air flow separation in cases of extreme wave slope and surface roughness. We will seek to recognize signs of such phenomena in the data and estimate their influence on the wave field evolution.

The PI closely collaborates with other members of the project's team. The experimental component is carried out with Carl Friehe (UCI). The work on data assimilation, surface and boundary layer air flow modeling will be done with Eric Terril (UCSD) and Peter Sullivan (NCAR).

WORK COMPLETED

The trial cruise of this project was carried out in order to work out the essential experimental steps, validate the software and test the performance of the instruments. It was conducted between July 6th and July 13th, 2009 from the R/P FLIP, drifting and changing its heading freely over about 30 nautical miles. Two days for towing, one day of deploying the booms, two days for instrumenting the mast and one day for bringing the instruments back in, reduced the week at sea down to two days for collecting data. The platform’s path is shown in Figure 1, where the data gap corresponds to the period of connecting the instruments' cables to the data collection system and testing the signals. Figure 2 shows the instrumented mast and the deployed instruments are listed in Table 1. Total of 28 instruments were tested and the number of variables sampled continuously was 105.

Table 1. List of instruments deployed during the trial experiment.

Instruments	Quantity measured	Height/Location
5 Cups	Wind speed	2 at 6.9m, 2 at 7.9m
2 Vanes	Wind direction	6.9m, 13.30m
RMY Propeller	Wind speed & direction	6.9m
EG&G Dew point	Dew point temperature	15.35m
Krypton Hygrometer	Atm. humidity	13.30m
Infrared SST	Sea surface temperature	————
2 Sonic Anemometers	Wind velocity, Air temperature	3.7m, 13.30m
Motion at Sonic 2	Accelerations & Ang. rates	13.30m
FLIP's Gyroscope	Heading	————
4 Pressure Pairs	Atmospheric pressure	2.06m, 3.70m, 8.78m
GPS Unit	GPS location and timing	————
2 Thermistors	Air temperature	15.35m
Inertial Nav. Unit	GPS position, Motion	Tower

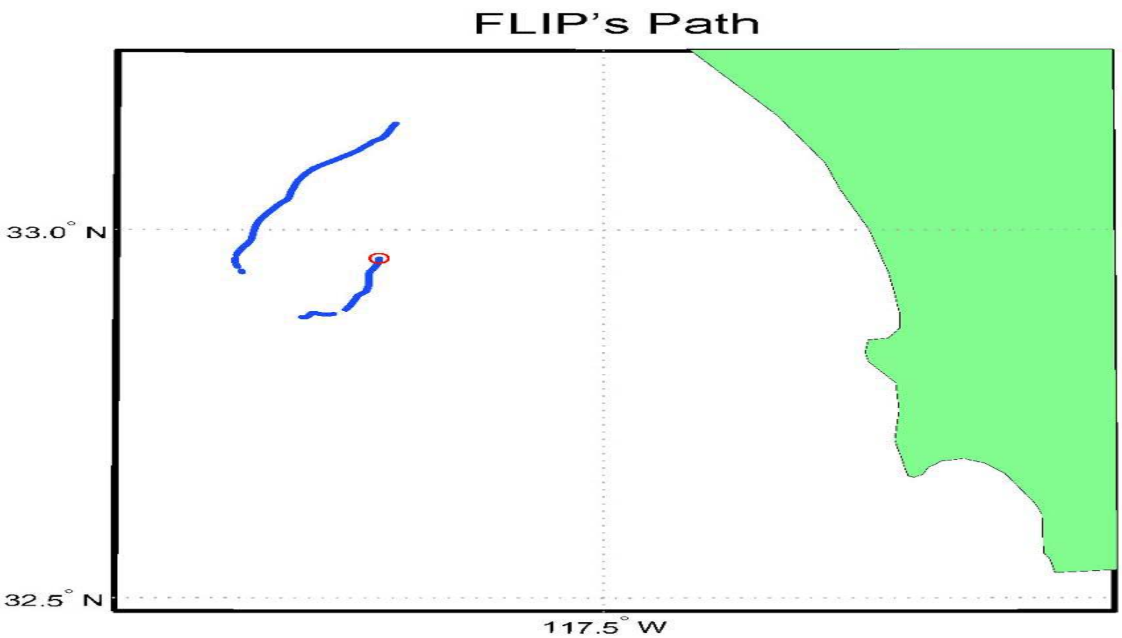

Figure 1. A The path of the drifting R/P FLIP during the trial experiment, as registered by an onboard GPS tracking device.

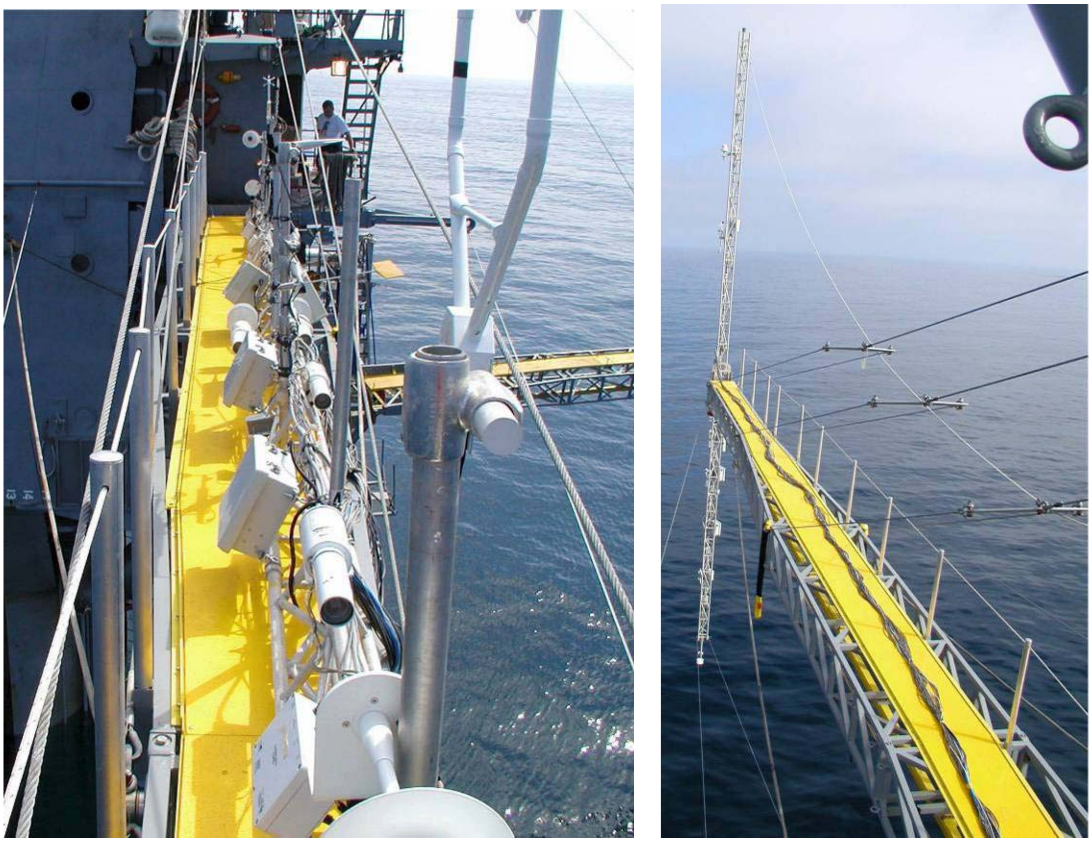

Figure 2. The instrumented mast on the port boom (left) and deployed vertically (right).

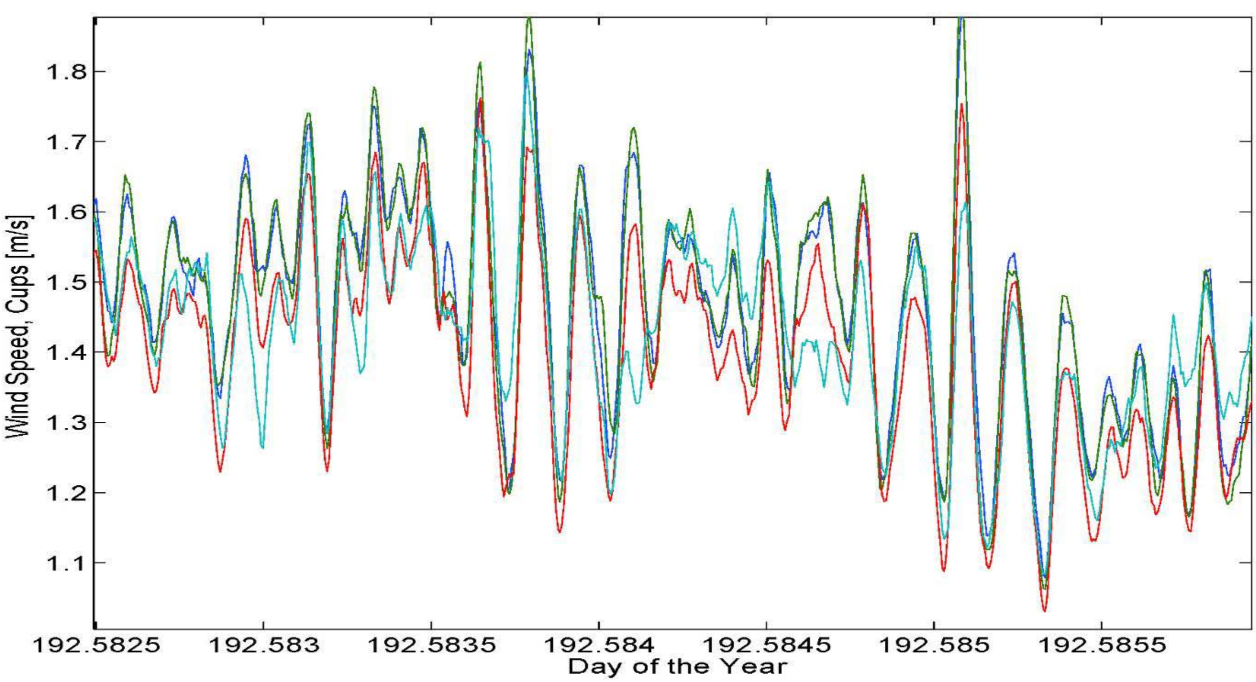

Figure 3. Wave-induced fluctuations of the wind speed, as registered by four of the cup anemometers. This wave signature is directly observable in the wind velocity signals in light winds. With increase of the wind speed the turbulence blurs the wave effects and a separation

RESULTS

Among the essential components of the meteorological array were the instruments measuring airflow velocity (sonic anemometers, cups, vanes), pressure sensors, and the units for GPS tracking and inertial navigation.

Both the sonic anemometers and the cups have clearly registered the wave modulation of the wind velocity, responsible for the wave generation, Figure 3. Instances of that modulation are directly observable in the signals in light winds. At higher winds, although the wave-induced fields still exist and are the key flow component that carries the wind-wave interaction, they are blurred by the more intense turbulence, and their identification requires wind velocity filtering (Hristov *et al.*, 2003).

Figure 4 shows measurements of atmospheric pressure, with wave signature clearly present. The signals demonstrate virtually no vertical decay of the wave effects in pressure, a distinct feature of the pressure field predicted by both analytic and numerical modeling (Hristov *et al.*, 2003). Such a feature is inconsistent with the traditional assumption of exponential decay of the wave-induced pressure with height, incorrectly used to extrapolate atmospheric pressure measurements down to the surface. Almost no turbulence is observable in the pressure signals, indicating low efficiency of the random force mechanism for wave generation (Phillips, (1957)). According to expectations, the two pressure instruments at level 5 track consistently. Temperature measurements from the pressure units were found to depend on the radiative solar heating. To reduce such dependence the units are upgraded to ensure more aspiration.

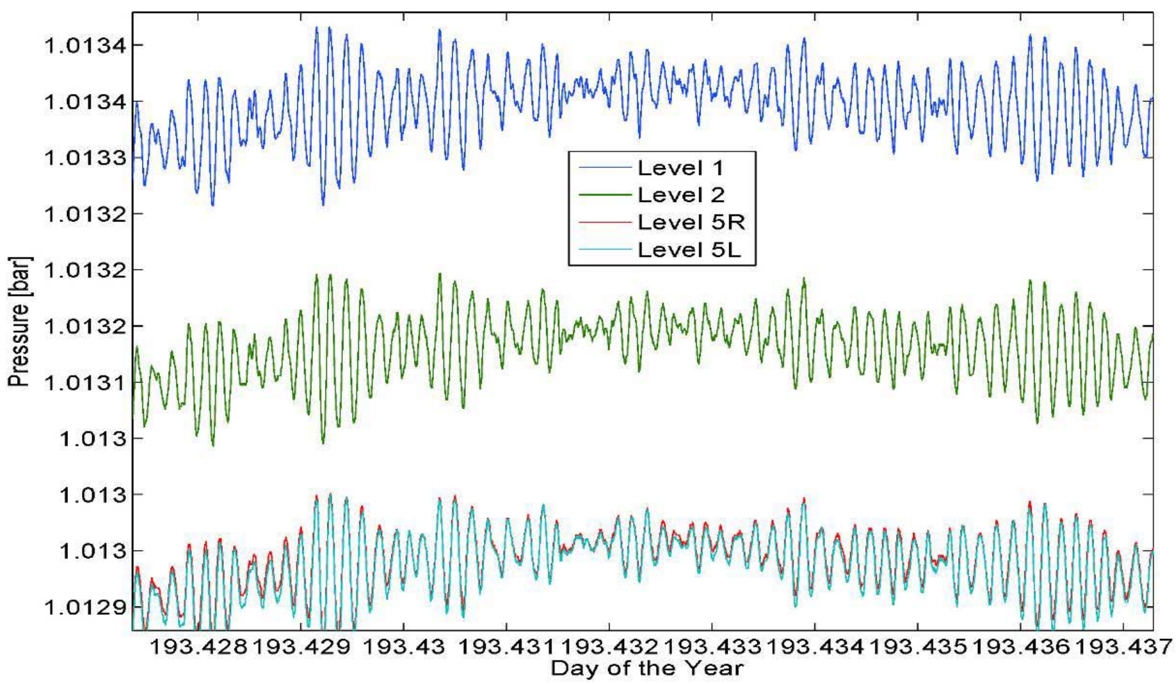

Figure 4. Wave-induced fluctuations from four pressure sensors, with height from the surface distinguished by the color; blue corresponds to the instrument closest to the surface, green being the next in height, and red an cyan are at the same level, highest from the surface.

The platform heading was recorded simultaneously from the FLIP's gyroscope and the inertial navigation unit. Although the two track consistently for 40 hours, there is an instance of failure of the inertial navigation unit. We currently conduct extensive testing to determine the cause of failure and ensure uninterrupted operation.

IMPACT/APPLICATIONS

The results of this research are expected to advance the basic science of the air-sea interaction and will be applied to operational models for short-term wave modeling and forecasting. The information on the structure and dynamics of the marine atmospheric boundary layer (MABL) and the statistics of the ocean surface will advance the description and modeling of signal propagation over the ocean. The profound physical similarities between propagation of radar signals over the ocean and acoustic signals in the water will extend possible applications to the acoustic domain. Since the MABL structure and dynamics is also essential in designing and modeling the performance of flying objects operating close to the ocean surface, such engineering applications of this project results are foreseeable as well.

RELATED PROJECTS

The PI is unaware of any related projects.

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